ACC/AUT Mountain Biking Injury Prevention Literature Scoping Project

Photo acknowledgement: Haydn Kevin Bradfield, 2017

A technical report to ACC

30th April 2017

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INJURY RISK FACTORS AND COUNTERMEASURES FOR MOUNTAIN BIKING

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The question
What are the risk factors and effective injury prevention countermeasures for mountain biking injuries?

What we did
Examined evidence from academic journals and web sources for risk factors and effectiveness of injury prevention countermeasures for mountain biking.

What we found
- Of 687 journal articles screened for mountain biking injury risk factors and counter measures, 12 journal articles met inclusion criteria and were reviewed.
- No studies evaluated the effectiveness of injury prevention strategies via the best scientific design (i.e. controlled interventions).
- Only two studies[1, 2] provided quality information on risk of injuries (i.e. odds ratios). There is increased risk of injury with increased speed, riding a new bicycle, jumping, riding downhill or dual slalom, and from wearing more protection *(note more experienced riders wear more protection but ride faster, and do more downhill and jumping).* Falling forward over the handlebars is the most frequent injury cause.

Key risk factors to focus on for injury prevention interventions that may help reduce the risk of injury include:
- **Physiological factors** - muscular strength and endurance to reduce arm and leg fatigue, and to improve better decision making.
- **Biker skill related factors** - teaching mountain bikers how to keep control of the bike under a variety of conditions including downhill, and how to ride within their ability, including not having excessive speed.
- **Psychological factors** - improvement of judgement skills, improving attentiveness to signs, trail conditions and obstacles, and reducing alcohol and drug use.
- **Safety gear/protector use related factors** - strongly encouraged use of body armour.
- **Bicycle technical related factors** - maintenance of bicycles, and correct fit of the bicycle for the ability of the mountain biker.
- **Trail related factors** - good trail environmental conditions, and reduction of potential obstacles such as other riders and non-riders.

Countermeasures that might be effective based on other sport interventions (given there were no mountain biking specific interventions) and the E's of injury prevention could include:
- **Enforcement** of a consistent national trail standard;
- **Engineering** by provision of protective gear including body armour to reduce shoulder/clavicle injuries, rental and visitors' bikes maintenance;
- **Environment** via signage to enable better match of ability and terrain by mountain bikers, terrain condition improvement, daily grooming and appropriate rating of trails, on-trail signage to warn about obstacle and danger zones and potentially bypass routes;
- **Education** for mountain bikers on risk factors and their countermeasures such as equipment maintenance information, and education sessions for beginners on risk-taking behaviour ("riding beyond one's ability": excessive speed, jumps, riding inadequate trails) and learning appropriate mountain biking techniques (braking, cornering, jumping); body armour with shoulder protection recommended for advanced riders.

What we suggest happens next
Injury prevention initiatives for mountain bike parks in New Zealand should be discussed by the key stakeholders, with a plan developed for implementation and evaluation of effectiveness.

TECHNICAL SUMMARY OF INJURY RISK FACTORS AND COUNTERMEASURES FOR MOUNTAIN BIKING

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Background

- There have been concerns raised about the frequency and cost of mountain biking injuries in New Zealand. Targeted injury prevention countermeasures have the potential to help reduce the incidence and severity of recreational mountain bike injuries if they are based on an understanding of injury mechanisms and associated risk factors. Mountain bike parks could benefit from easily implemented and cost effective injury prevention countermeasures that are effective in reducing injury rate and severity.

Purpose

- To provide evidence for risk factors and effectiveness of injury prevention countermeasures for mountain biking from journal and grey (web documents) literature.
- The outcomes of the review are to provide input into possible injury prevention initiatives for mountain bike parks in New Zealand.

Methods

- A search of electronic peer-reviewed journal literature was conducted for mountain bike risk factors and mechanisms using key words 'mountain bik*', 'injur*', 'epidemiology', 'risk', 'prevention'.
- Given the limited number of studies for any risk factor, an inclusive approach was taken. Papers were selected based on title, then abstract and finally text. Of 687 journal articles screened for mountain biking injury risk factors and counter measures, 12 journal articles that met inclusion criteria were reviewed.
- A search of grey literature on Google using keywords (mountain biking, injury prevention, injury risks, safety) and a search of sources cited by identified webpages or the peer-reviewed articles were reviewed.
- Institutional websites (cycling federations, mountain biking associations, mountain biking parks) for New Zealand, Canada, Australia, Wales, Scotland, England, and USA were viewed.
- A Haddon's matrix conceptual framework for injury causation[3] was used to extract themes and create evidence summaries from the peer-review journal material and the grey literature material.

Results

- Only two studies[1, 2] provided odds ratios for injuries.
- Romanow et al., 2014[1] reported statistically significant increased odds of severe injury with speed faster than usual (OR=2.5, 95% CI: 1.2, 5.3 /aOR=2.8; 95% CI: 1.3, 6.1). Other variables of new bicycle ridden less than 10 times (OR=1.9, 95% CI: 0.9, 4.1 /aOR=2.1; 95% CI: 0.9, 4.8), jumping (OR=2.3, 95% CI: 0.7, 7.4) or wearing more protection (helmets excluded) (aOR=1.6; 95% CI: 0.7, 3.4) were statistically insignificant.
- Kronisch et al., 2002[2] reported women have increased odds of injury (OR 1.94, 95% CI 1.17 to 3.08), for all events, levels and age combined, especially in dual slalom (OR 4.03, 95% CI 1.21 to 12.15) and increase odds of fracture (OR 4.17, 95% CI 1.81 to 9.29, all events), especially in downhill and dual slalom. Significant difference in the incidence of injury for men downhill events, with pros sustaining more injuries than amateurs (OR; 3.50, 95% CI 1.49 to 7.71). However, there were no differences in the types or mechanism of injury (Fall forward over the handlebars (73.0%), Fall to the side (24.7%), Fall backward after colliding with a pole or barrier (2.2%)).
- Twelve mountain biking studies provided information on risk factors from epidemiology study designs.

Conclusions

The scoping review of peer-reviewed and grey literature, used the Haddon's matrix conceptual framework for injury causation to identify a number of recreational (general public use of bike parks, not racing) mountain biking injury risk factors that may be addressed by injury prevention strategies. However, further research with intervention studies are needed to confirm the effectiveness of countermeasures.

Key risk factors to focus on for injury prevention interventions that may help reduce the risk of injury include:

- **Physiological factors** - muscular strength and endurance to reduce arm and leg fatigue, and to facilitate decision making.
- **Biker skill related factors** - teaching mountain bikers how to keep control of the bike under a variety of conditions including downhill, and how to ride within their ability, including not having excessive speed.
- **Psychological factors** - improvement of judgement skills, improving attentiveness to signs, trail conditions and obstacles, and reducing alcohol and drug use.
- **Safety gear/protector use related factors** - strongly encouraged use of body armour.
- **Bicycle technical related factors** - maintenance of bicycles, and correct fit of the bicycle for the ability of the mountain biker.
- **Trail related factors** - good trail environmental conditions, and reduction of potential obstacles such as other riders and non-riders.

Countermeasures that might be effective based on other sport interventions (given there were no mountain biking specific interventions) and the E's of injury prevention could include:

- **Enforcement** of a consistent trail standard;
- **Engineering** by provision of protective gear including body armour to reduce shoulder/clavicle injuries, rental and visitors' bikes maintenance;
- **Environment** via signage to enable better match of ability and terrain by mountain bikers, terrain condition improvement, daily grooming and appropriate rating of trails, on-trail signage to warn about obstacle and danger zones and potentially bypass routes;
- **Education** for mountain bikers on risk factors and their countermeasures such as equipment maintenance information, and education sessions for beginners on risk-taking behaviour ("riding beyond one's ability": excessive speed, jumps, riding inadequate trails) and learning appropriate mountain biking techniques (braking, cornering, jumping); body armour with shoulder protection recommended for advanced riders.

It is recommended that no further statistical analysis of the peer-reviewed literature (i.e. meta-analysis) and relevant grey literature is required for this project, given the limited literature found in the scoping review specifically for mountain biking.

Injury prevention initiatives for mountain bike parks in New Zealand should be discussed by the key stakeholders, with a plan developed for implementation and evaluation of effectiveness.

INTRODUCTION

There have been concerns raised about the frequency and cost of mountain biking injuries in New Zealand. Mountain bike parks could benefit from easily implemented and cost effective injury prevention countermeasures that are effective at reducing injury rate and severity. Targeted injury prevention countermeasures have the potential to help reduce the incidence and severity of recreational mountain bike injuries if they are based on an understanding of injury mechanisms and associated risk factors. Most research still focuses on the incidence and causes/mechanics of injuries rather than implementing preventive measures.

Injuries result from a set of circumstances and pre-existing conditions that can be considered using Haddon's matrix [3] that provides a conceptual framework for injury causation. The temporal components of pre-event (primary injury prevention), event (secondary injury prevention) and post-event (tertiary injury prevention) phases are considered against human, agent and environmental factors.

When considering recreational mountain bike injuries, the key question is: *"Where will injury prevention interventions be most effective within this matrix?"* In selecting injury prevention countermeasures there needs to be:

- *identification* of the key problem hazards and resulting injuries;
- *consideration of design change* that ideally will not result in individuals having to take action each time the countermeasure is used;
- ensuring the countermeasure is *accepted for use by the participants*;
- ensuring there is a *positive cost to benefit ratio*; no unwanted side effects or misuse of the countermeasure; and
- the *effects* of the countermeasure *can be measured*.

The effectiveness of common injury prevention countermeasures such as education and behaviour change programmes, environmental/equipment design changes, and regulation/legislation changes need to be evaluated.

Purpose
The aim was to provide evidence from journal and grey (web documents) literature for risk factors and effectiveness of injury prevention countermeasures for mountain biking. The outcomes of the review are to provide input into possible injury prevention initiatives for mountain bike parks in New Zealand.

SECTION I: PEER REVIEW JOURNAL LITERATURE

Aim
The aim was to identifying relative evidence with a peer-reviewed journal search strategy to identify risk factors and to quantify evidence for effectiveness of injury prevention countermeasures.

Methods
A search of the literature was conducted for mountain bike injury risk factors and mechanisms. The PubMed, CINAHL, Web of Science, SPORTDiscus (only academic journals), Medline, the Cochrane Library (1465 articles) and Google Scholar databases, to February 2017 were searched for terms linked with the Boolean operators ('AND', 'OR', 'NOT'): 'mountain bik*', 'injur*', 'epidemiology', 'risk', 'prevention'.

Given the limited number of studies for risk factors, an inclusive approach was taken for the type of article and the year of publication. Injury and prevention studies prior to the 1990's were considered relevant today as we learn from our historical approaches. However, more recent studies would take into account changes in technology for equipment such as bicycle materials (carbon fiber versus metal), design (e.g. cleat/pedals) and protective gear (e.g. body armour).

The search of the databases resulted in 487 articles. The search on Google Scholar resulted in 37,400 articles, therefore the first 200 most relevant papers were extracted resulting in 687 articles. Using Endnote, automatic and manual removal of duplicates led to a list of 385 references.

Papers were selected based on title, then abstract and finally text. Manual searching of reference lists and the 'Cited by' tool on Google Scholar were used to identify additional articles. Papers were excluded if their content: (i) was unavailable in English or French; (ii) was unavailable in full text format; (iii) did not provide additional information for any of the identified sections and subsections of this review. Inclusion criteria for all articles were: (i) reported data for risk factors on mountain biking injury rate or severity; or (ii) reported data for interventions to reduce mountain biking injury.

For subsequent analysis exclusion criteria were: (i) did not provide odd ratios (OR) or relative risk (RR) and/or other statistics allowing assessment of the effect factors on injury (or data to enable their calculation e.g., cohort studies using only absolute and not relative injury rates); (ii) data reported only death rather than injury rate. In summary, articles were initially excluded if they were epidemiological studies with no injury risk focus, or provided no data allowing risk statistics to be calculated, or were intervention studies without an injury risk factor focus or did not provide enough data for the odds ratio analyses.

Screening of the titles allowed exclusion of references in the following categories: off-topic (articles on performance, psychology, environment, n = 167 articles), not specific to MTB (Various sports, road cycling, n = 38), case series and case reports (n = 20), duplicates (n = 7), language (n = 1). A further 103 articles were excluded (Figure 1) based on their abstract: off topic (n = 34), not specific to MTB (MTB injuries mixed with no distinction possible with other types of biking, n = 31), not peer-reviewed (n = 15, those were put aside to be treated with the grey literature), abstract not available (n = 11), case series and case reports (n = 7), duplicates (n = 5).

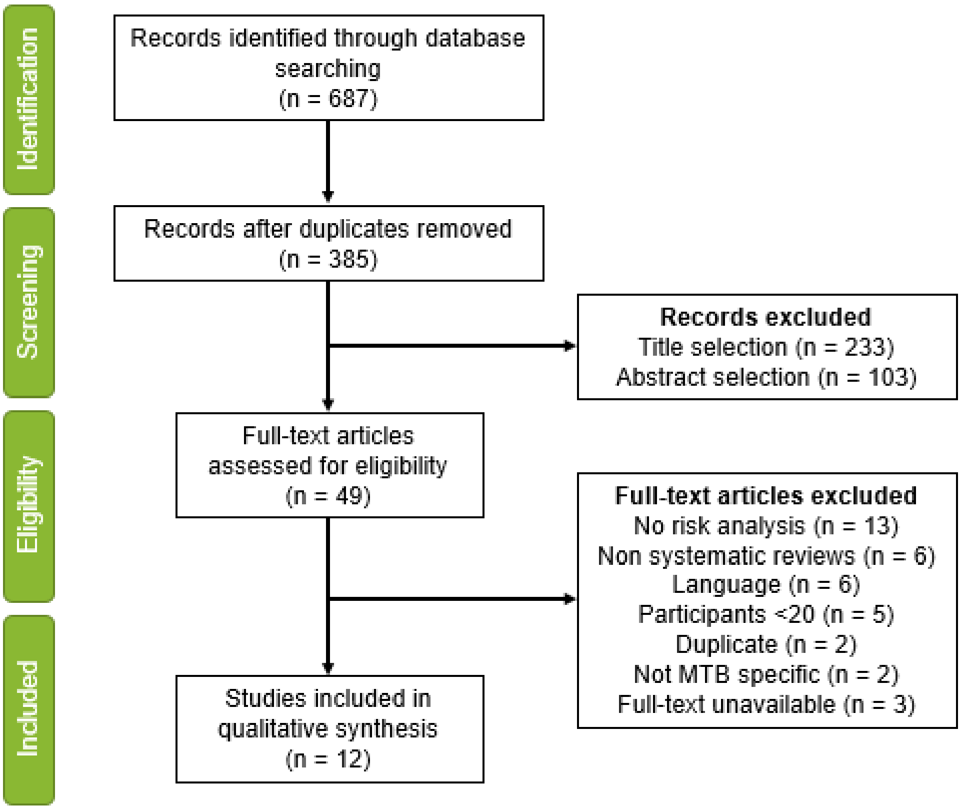

Figure 1. Flow of information through the scoping exercise

Out of the 49 references selected for full-text analysis, one met all initial inclusion criteria. Most studies presented a cross-sectional, mostly retrospective design, and described injury type, location, and mechanism of injury. No intervention studies were found, and very few studies were designed to identify potential risk factors. An Emergency Department based case-control study, provided odds ratios for speed, bicycle, jumping, protective gear. Several studies did not differentiate recreational from competitive mountain biking. Several authors showed that the pattern of injuries, as well as the mechanisms (e.g. being thrown over the handlebar), were similar for recreational and competitors.

Due to the limit in available information and the intent of the document we adapted the inclusion criteria to be more flexible so the ACC business unit had a document that would inform their discussions regarding injury prevention at mountain bike parks. We expanded from the original exclusion of studies based on whether or not they had odds ratios or risk ratios. We included qualitative papers to help build context around the subject. Studies that included a comparison of recreational with competitive mountain biking were included. Studies were excluded if they had small sample sizes (n<20).[4, 5] Narrative reviews were excluded. Figure 1 shows the final flow of information through the systematic review resulting in 12 studies being included in the qualitative synthesis. As the literature was limited in quality and reporting, the next step of a full meta-analysis could not be conducted.

Study limitations

There was a large range in sample size (n=49 to 4,624), injury risk factors investigated (e.g. fatigue, speed, inattentiveness), definition of injury risk factor categories and limited injury risk factor statistics (e.g. RRs, ORs, Pearson correlations) utilised throughout the studies. This large variation in definition of outcomes and factors between studies made combined analysis difficult for some risk factors. For example, "head injury" was defined as serious (e.g. severe traumatic brain injury with intracranial bleeding with edema) in some papers, whilst a "head/face injury" (e.g. minor facial injury including a serious fractured nose) was defined as serious in other papers. The diagnosis of injuries in studies may have been provided by a range of medical personnel such as paramedics or physicians. Most studies did not adjust for co-variates such as age, gender, socioeconomic, BMI etc.

Results

No studies were found that evaluated the effectiveness of injury prevention strategies via controlled interventions.

There was only one study with cases and controls.[1] Only two studies[1, 2] provided odds ratios for injuries.

Romanow et al., 2014[1] reported statistically significant increased odds of severe injury with speed faster than usual (OR=2.5, 95% CI: 1.2, 5.3 /aOR=2.8; 95% CI: 1.3, 6.1). Other variables of new bicycle (ridden less than 10 times) (OR=1.9, 95% CI: 0.9, 4.1 /aOR=2.1; 95% CI: 0.9, 4.8), jumping (OR=2.3, 95% CI: 0.7, 7.4) or wearing more protection (helmets excluded) (aOR=1.6; 95% CI: 0.7, 3.4) were statistically insignificant.

Kronisch et al., 2002[2] reported women have increased odds of injury (OR 1.94, 95% CI 1.17 to 3.08), for all events, levels and age combined, especially in dual slalom (OR 4.03, 95% CI 1.21 to 12.15) and increase odds of fracture (OR 4.17, 95% CI 1.81 to 9.29, all events), especially in downhill and dual slalom. Significant difference in the incidence of injury for men downhill events, with pros sustaining more injuries than amateurs (OR; 3.50, 95% CI 1.49 to 7.71). However, no differences in the type or mechanism of injury. Injury mechanism: Fall forward over the handlebars (73.0%), Fall to the side (24.7%), Fall backward after colliding with a pole or barrier (2.2%).

The details of the 12 mountain biking studies that provided information on risk factors from epidemiology study design are shown in Table 1.

Modifiable risk factors such as protective gear use, ability, alcohol use and terrain condition were examined in a number of prospective epidemiology studies[6] using hospital data from Scotland,[7] and Canada,[1, 8] or mountain bike park racing event data from the USA.[9, 10] Retrospective epidemiological studies of hospital data were conducted in the USA[11] and Canada.[12, 13] Retrospective questionnaire-based survey data from the USA,[14] and from a multi-country study for Germany, Austria, and Switzerland[15] were gained by asking participants about their experiences of what led to the injury from mountain biking.

Table 1. Mountain biking studies that provided information on risk factors and injury prevention strategy effectiveness

Study	Study design	Focus	Participants characteristics, age (mean ± SD), MTB ability level	Injury reduction and mechanisms	Author's comments and critiques
Romanow et al., 2014[1]	Case-control study, at Emergency Departments, with interviews, 2008-2010, Canada.	Severe injuries sustained in a MTB park, recreational only.	**Case:** 31 patients hospitalized (7% of total) for 36 injuries, 19 ±13.2 yr. (63% are ≤ 14 yr.), 84% males. **Controls:** 378 patients seen for 465 injuries and discharged from the ED, 15 ±8.2 yr., 90% males. 77% of cases and 74% of controls previous MTB park experience.	Increased odds of severe injury with: Speed faster than usual (OR=2.5, 95% CI: 1.2, 5.3 / aOR=2.8; 95% CI: 1.3, 6.1); New bicycle (ridden less than 10 times) (OR=1.9, 95% CI: 0.9, 4.1 / aOR=2.1; 95% CI: 0.9, 4.8); Jumping (OR=2.3, 95% CI: 0.7, 7.4); Wearing more protection (helmets excluded) (aOR=1.6; 95% CI: 0.7, 3.4).	Age: One of the ED participating in the study is a paediatric hospital, which explains the very young population. The authors report that other bicycle studies have shown that those 10-14 years old have higher injury rates. Protective gear (helmets excluded): "A greater proportion of cases than controls reported wearing upper extremity protection (23% vs. 11%, p=0.03)". Risk compensation theorem explains the difference: those who wear protective equipment could be more inclined to engage in risky behaviour, with or without experience and ability as linking factors. It could also suggest that "certain types of equipment protect against minor injuries, but may not offer as much protection for more severe injuries such as fractures." Previous experience in terrain park did not differ between cases and controls (77.4% and 74.3% previous experience, respectively). Note: the complete data collection form is available as an appendix in the article.
Kronisch et al., 2002[2]	Prospective study at NORBA MTB competitions (highest national-level racing series), 1994-2001, USA.	Moderate to severe injuries preventing the rider to finish the race, and requiring first aid, physician or hospital consult. Includes cross-country (XC), downhill (DH) and dual slalom (DS).	N=93 injured competitors (0.5% of all competitors, 86% males). Males (76%): 28.4 yr. (range 15-59), Females: 30.8 yr. (range 22-52). No significant differences for individual years, so results are from the 8 years combined.	Women have increased odds of injury (OR 1.94, 95% CI 1.17 to 3.08), all events, levels and age combined), especially in DS (OR 4.03, 95% CI 1.21 to 12.15) and increase odds of fracture (OR 4.17, 95% CI 1.81 to 9.29, all events), especially in DH and DS. Significant difference in the incidence of injury for men downhill events, with pro sustaining more injuries than amateurs (OR; 3.50, 95% CI 1.49 to 7.71). However, no differences in the type or mechanism of injury. Injury mechanism: Fall forward over the handlebars (73.0%), Fall to the side (24.7%), Fall backward after colliding with a pole or barrier (2.2%).	The overall injury rates were similar in the CC, DH, and DS races (0.43%, 0.44%, and 0.57%, respectively). The difference in injury rate between gender is more pronounced in DS races. "A higher percentage of women reported loss of control of the bicycle as the cause of their accident (54.5% versus 28.2%, p=0.04), and a higher percentage of men reported bicycle mechanical problems as the cause of injury (21.1% versus 0.0%, p=0.02)." Age and skill categories differed from year to year according to NORBA classification system, making it difficult to compare injury rates. Competitive data.

Aitken et al., 2011[7]	Prospective study, care facilities (First aid station to trauma centre), 1 year 2007-2008, Scotland. Use of other surveys to describe non-injured population.	Minor, moderate and severe, acute injuries sustained while mountain biking in Glentress MTBing centre.	Non-injured: 400 MTBikers, 83% males, 32 yr. Injured: 202 (0.15% of all MTBikers), 88% males, 31.5 yr. Most commonly injured group: males 30-39 yrs.	Injury rate was higher in men (1.64 per 1000 biker exposures) than in women (1.08). Injury incidence and trail grading (by increasing difficulty): Green 10.9 injury/100,000/year, Blue 28.1, Red 42.3, Black 22.5, Freeride park 97.5. Significant correlation between incidence of dislocation and advancing age (p=0.001, N=14). Use of lower limb body armour associated with fewer lower limb injuries (p=0.04), use of gloves associated with fewer injuries (p=0.05).	"All head-injured individuals had been wearing a helmet at the time of injury. Modern helmets are designed to absorb kinetic energy and shatter on impact; this occurred in 71% of cases. Of those individuals whose helmet shattered, 68% reported no head injury". Helmet type (XC, Full face DH, XC with face, Skater) does not influence head injury prevalence. The paper can be criticised in terms of the data for proportion of injuries according to type of pedal and bike characteristics, as numbers don't match the total number of injuries. Instead of representing risk factors, they represented riding styles: "bikers using flat pedals are often said to favour them to attempt tricks and jumps". An uninjured population was used as the control group, however, riding style and risk-taking behaviours can bias results. No OR or RR but some data comparing control and injured.
Becker et al., 2013[6]	Prospective study, with monthly e-mail based surveys, April-September 2011, Germany, Luxembourg, Switzerland and Austria.	All acute injuries, mild to severe, sustained while Downhill MTB (competitive or recreational). Injury defined according to Fuller et al. as any injury of an athlete resulting from training or competition, irrespective of medical treatment requirement or time loss from sports activities.	N=249 at beginning of study, 200 at end, for 494 injuries. 23.5 ±6.8 yr. (range 14-53), 1% beginners, 25% advanced, 63% experts, 11% professionals. Mean (±SD) years riding: 4.0 ±3.2 yr., hours/month riding: 13.1 hr. Exposure: 10% of competition participation.	Accidents happened in a curve (43%), during jumps (32%) and sloping terrain (32%). Terrain ridden at the time of injury: soil (63%), stones (45%), roots (33%). Landing zone after a fall: constituted by soil (66%), stones (44%), roots (24%). Injury mechanisms: Riding errors (72%), Poor trail conditions (31%), Unforeseen trail obstacle (16%), Over fatigue (10%), Weather (8%), Wrong choice of materials (8%), Poor sight (4%), Technical failure (3%), Collision with other driver (2%). Circumstances of incidents: Fall over the handlebar (32%), Wrong landing (17%), Sliding (16%), Slipped of the pedal (12%), Front wheel sliding (12%), Side slipping (10%), Collision with tree (9%), Clinging (7%), Rolling over (2%). Note: multiple circumstances possible. Experts were at higher risk of getting injured compared to professionals (OR 1.34; 95% CI, 1.02 to 1.75; p=0.03). Competition led to more injuries than practice (OR 1.53; 95% CI, 1.16 to 2.01; p=0.01).	Time of injury: "58% of injuries occurred in the middle of a downhill day whereas the rest of the injuries was distributed evenly between the beginning (21%) and the end (20%) of the day." "In 31% of the incidents the trail conditions were rather poor (greater irregularities and holes, excessive roots, slippery underground) and 30% of the injuries occurred despite rather good trail conditions (small irregularities and holes, scattered roots, no slippery underground)." "Weather conditions at the time of injury were mainly very good (51%), followed by rather good weather (29%)." Interesting data on the conditions of the accident, like the type of terrain on which the rider lost control, or the weather conditions, but these data at the moment of accident were not compared to the overall prevalence, so only descriptive. Well-designed prospective study, but OR only on professional/expert riders.

Bush et al., 2013[8]	Prospective study at emergency departments, 1 year, Canada.	Moderate to severe hand and wrist injuries acute injuries sustained while MTBiking.	N=217 injuries (114 hand and 103 wrist injuries). 29.3 yr., range 16-64. 86% males. Mean years riding: 6.4 yr., Self-reports of skill level: 42% intermediate skills, 40% experts and 18% beginners.	Bike characteristics: Full suspension downhill bikes (50%), front suspension bikes (29%), full suspension cross-country bikes (16%), and no suspension (3%). Protective gear: 96% wearing a helmet, and 51% armour on their arms. Equipment failure reported in 5% of accidents. Injuries occurred in MTB park (73%), trails (18%) and hills (5%). At time of accident, riders were riding downhill (60%), jumping (20%), biking on the level (10%), doing a trick (5%), or riding uphill (4%). Injury mechanisms: Forward falls (70%), sideways falls (24%) and backward (2%). Average duration of riding before injury was 2 h and 10 min.	The paper provided descriptive data, but no comparison to a control group or to frequentation data. Average time of riding before injury was interesting, but would be better if there was variance or distribution. No OR or RR.
Chow & Kronisch, 2002[10]	Prospective study at MTB racing events (NORBA DH, XC, DS), 1994-1998, USA.	All injuries while competing, preventing from completing the race. Cross-country, downhill, dual slalom combined.	N=97 MTBikers. 28.3 yr. (range 15-59). 74% males.	Grade ridden at the time of injury: Downhill (85.6%), Flat (8.2%), Uphill (3.1%), N/A (3.1%). Cause of fall: Loss of control (32%), Collision with another rider (16.5%), Mechanical problem (15.5%), Loss of traction (14.4%), Collision with stationary object (7.2%), Other/unknown (14.4). Direction of fall: Forward (64.9%), Side (24.7%), Other/unknown (10.3). Falls forward (over the handlebars), compared to fall to the side, led to more emergency department evaluations (60% vs 29%, p=0.02), higher ISS (3.4 vs 1.7, p=0.001), more injuries to the head/face/neck (56% vs 8%, p=0.001), less injuries to lower extremity (57% vs 88%, p=0.01)	"Collisions led to injuries that were no more severe than injuries without a collision" and similar pattern of injuries. No differences depending on mechanism (loss of control, loss of traction, mechanical failure). No OR or RR.
Kronisch & Rubin, 1994[9]	Cross-sectional survey, questionnaire-based, on members of off-road cycling clubs, USA.	All MTB injuries in previous 12 months, then most serious detailed. Injury considered significant if cyclist sought medical attention, was unable to ride for 1 day, and was traumatic.	N=265 participants, incl. 85.7% reporting injuries: 54 significant injuries (and 421 minor injuries not considered). Of 265 participants: 30.2 yr. (range 10-56), 75.5% males. Mean MTB experience 4.1 yr., average 3.3 rides/week. 19.7% recreational, 30.3% fitness, 44% competi-	Variables associated with significant injuries incidence (univariate): Loss of control (p < 0.01), High-speed descent (p < 0.05), Competitive activity level (p < 0.01). Variables associated with significant injuries incidence (multivariate): Competitive activity: aOR: 4.24 (p < 0.0001), Uphill riding: aOR: 0.24 (p < 0.001).	No association with rider's age, sex, riding history, equipment usage, cross training, medical problems, time of day, length of ride, prior injury, terrain type, specific manoeuvres. The population sample seems skewed towards an elite group of cyclists (participation in competitions, cost of the bike). Half of population participates in competition.

			tive, 1.5% pro.		
Nelson & McKenzie, 2011[11]	Retrospective study, using NEISS data (emergency departments), 1994-2007, USA.	All injuries sustained while using a mountain bike (passengers excluded). No distinction recreational/ competition.	N=4,624 cases of MTB-related injuries. Mean age 29.8 ±13.3 yrs. (range 8-97 yr.), 80.8% males, most commonly injured group: males 20-39 yr.	Gender differences: Males more dislocations than females (IPR, 1.9; 95% CI, 1.1 to 3.4); Males more shoulder injuries (IPR, 1.9; 95% CI, 1.6 to 2.3); Males fewer lower-extremity injuries (IPR, 1.3; 95% CI, 1.0 to 1.6); Females were more frequently hospitalized (IPR, 1.4; 95% CI, 1.1 to 1.7). Age: 8-13 yr. more soft tissue injuries than ≥14 yr. (IPR, 1.3; 95% CI, 1.1 to 1.5); 14-19 yr. more TBIs than 8-13 yr. and ≥20 yr. (IPR, 2.0; 95% CI, 1.6 to 2.5); 20-39 yr. more dislocations than 8-19 yr. and ≥40 yr. ((IPR,2.0;95% CI,1.3 to 2.8); ≥40 yr. more fractures than <40 yr. (IPR, 1.3; 95% CI, 1.2 to 1.4); 8-13 yr. more upper extremity injuries than ≥14 yr. (IPR, 1.3; 95% CI, 1.2 to 1.5); 14-19 yr. more head injuries than 8-13 yr. and ≥20 yr. (IPR, 2.0; 95% CI, 1.6 to 2.5); ≥40 yr. more trunk injuries than 8-39 yr. (IPR, 1.6; 95% CI, 1.4 to 1.8); 8-13 yr. more injuries caused by contact with bike than ≥14 yr. (IPR, 1.9; 95% CI, 1.3 to 2.7), and by being hit by something (IPR, 3.4; 95% CI, 1.9 to 6.4); ≥40 yr. more frequently hospitalized than 8-39 yr. (IPR, 2.3; 95% CI, 1.8 to 2.9). Injury mechanisms: Fall (69.9%), Thrown (14.1%), Hit/strike (7.0%), Contact with bike (5.1%), Hit by/struck by (1.6%), Other (2.3%). Falls led to more upper extremity injuries (IPR, 1.9; 95% CI, 1.7 to 2.2); Being thrown from bike led to more shoulder and clavicle injuries (IPR, 1.5; 95% CI, 1.3 to 1.8), and more TBIs (IPR, 2.2; 95% CI, 1.7 to 2.8); Hitting an object while riding led to more face injuries (IPR, 2.0; 95% CI, 1.5 to 2.7) and head injuries (IPR, 1.8; 95% CI, 1.3 to 2.6); TBIs and fractures required more hospitalizations (IPR, 3.8; 95% CI, 2.6 to 5.4; IPR, 2.3; 95% CI, 1.8 to 2.9, respectively); Head and trunk injuries required more hospitalization (IPR, 3.0; 95% CI, 2.1 to 4.4; IPR, 3.5; 95% CI, 2.8 to 4.5, respectively); Being hit by something and being thrown from bike required more hospitalizations (IPR, 4.1; 95% CI, 2.3 to 7.4, IPR, 1.4; 95% CI, 1.1	Data on mechanisms of injury in Appendix 1 - supplementary online data. Retrospective study and likely mixed recreational and competition.

				to 1.8, respectively).	
Chow et al., 1993[14]	Retrospective, questionnaire-based survey, USA.	Most recent injury sustained while off-road biking (incl. some injuries on paved road), defined as "the presence of pain, discomfort, or disability," and rated in severity according to required treatment.	N=225 injuries, 36.2 ±9.4 yr., 82.8% males, mean (±SD) years riding: 4.2 (±2.3) yr., hours/week off-road riding: 5.0 (±3.1) hr.	Type of terrain ridden at moment of injury: dirt (42.7%), combination of dirt, rocks, sand (26.7%), rocks (12.9%), paved (12.4%), sand (1.8%), other (3.6%). Grade ridden at time of injury: Moderate downhill (40.0%), steep downhill (34.2%), flat (15.1%), moderate uphill (5.3%), steep uphill (3.6%). Factors contributing to accident, as declared by participants: Excessive speed (36%), unfamiliar terrain (35%), inattentiveness (23%), riding beyond one's ability (20%), Intoxication - alcohol or marijuana (2.6%). "The more seriously injured group tended to ride more total hours each week (7.8 versus 6.3, P < .01) and more off-road hours each week (5.7 versus 4.8, P < .05). When the circumstances of their accident were compared, the group that required a physician's evaluation were more likely to have their mishap while riding on paved terrain than off road (P< .01)."	"Injuries happened predominantly during the middle of the day (63.1%) in clear weather (89.3%) while the victim was riding primarily for recreation (86.7%)." (no additional precision). "Most of the injured fell without a preceding collision. In 23 collisions leading to injury, 13 were with stationary objects. The other 10 collisions were with a moving object, either another bicycle or a motor vehicle." (no additional precision). "55% of participants provided maintenance for their bikes 6 times a year or more [...] Equipment failure caused 7% of the accidents, most commonly the brakes and tires." The paper can be criticised in terms of the data on the type of terrain ridden and uphill/downhill at the moment of the injury were not related to the frequency of such terrain use, so were descriptive only. No OR or RR.
Gaulrapp et al., 2001[15]	Retrospective, questionnaire-based survey, Germany, Austria, Switzerland.	All injuries sustained in MTB (recreational and competition), defined as one preventing the practice of MTB for at least 1 day.	N=8133 injuries for 3474 respondents. 25 yr., range 8 -80 yr., 97.8% males. Mean (±SD) years riding: 3.7 yr., (minimum 1 yr. of experience as inclusion criteria); hours/week off-road riding: 8.6 hr. Regular participation in competition for 36% of participants.	Situation leading to injury: Slippery terrain (44%), False judgement of situation (34%), Excessive speed (33%), Collisions with other bikers, cars or animals (< 5%), fatigue (< 5%), Technical defect (< 5%).	"Participants in races did not show a higher injury rates than non-competitors." "Experienced athletes' higher incidence of joint and bone injuries than first year beginners". "There was no significant difference in the injury rate between beginners and athletes experienced more than 4 years. Participants in races did not show a higher injury rates than non-competitors." "Self-induced injuries affecting beginners and experienced athletes to a similar rate of approx. 75% each." "(14.3%) injuries were due to contact with some part of the bicycle; most collided with the pedals (57%), the handlebars (34%), or the bicycle frame (13%)." No OR or RR.
Roberts et al., 2013[12]	Retrospective study, on trauma patients, Southern Alberta Trauma Database, 1995-2009,	Severe injuries (ISS ≥ 12) sustained while street or mountain biking (median length of stay:	N=49 MTB injured patients, 209 street biking. Median age of MTB injured patients: 28 yr. (IQR 21-35). 87.8% males MTB.	Similar injury pattern across both groups. "Street cycling was associated with a significantly higher overall rate of admission for severe injury than mountain bicycling (1.8% v. 0.42%, p < 0.001)." Mechanisms of MTB injury: Fell off bicycle (55.1%), Lost balance, speed-related or other	"The time of day and season during which most bicycling-related trauma occurred was similar for street and mountain cyclists, with most injuries occurring in the morning or afternoon (24.0%) and in summer (53.9%) or spring (29.5%)." Data provided were date and time of injury, but there was no

	Canada.	6 days(IQR: 3-12)).		cause (55.1%), Fell while attempting a jump or trick (20.4%), Veered and fell off cliff, roadside or embankment (16.3%), Collided with a person, animal or object other than a motor vehicle (6.1%), Attempted to avoid a person, animal or object (0%), Rode down a hill at high speed (0%), Hit a speed bump (0%), Collided with a parked automobile (0%), Hit by a motor vehicle while bicycling (0%), Hit by a commuter train while crossing tracks (0%).	comparison to frequentation data, so descriptive only. No OR or RR.
Dodwell et al., 2010[13]	Retrospective study at a trauma centre (referral for spinal cord injuries), 1955-2007, Canada.	Severe to catastrophic spine injuries sustained while MTBiking (competitive and recreational). Mean length of stay: 16.9 days.	N=107 MTBikers (incl. 2 professionals), 3.8% of all admissions. Mean age: 32.7 yr. (95% CI 30.6-35.0), range 17-70. 95.3% males.	Mechanisms of injury: Being propelled over the handlebars (75.7%), other (22.4%). Collision with a tree 9.3%. 69.6% of injuries occurred on a trail and 30.4% occurred in a bike park. "There was no statistically significant difference in injury severity scores between helmet-compliant and helmet-noncompliant riders (p=0.95). "	"Of those propelled over the handlebars, 91.0% sustained direct impact primarily to their heads, and occasionally to the neck or face. The remaining 9.0% impact to the torso or thoracolumbar spine. Of those not going over the handlebars, 58.3% still sustained direct impact to the head/neck/face region." "Only 1 injury was documented as alcohol-related. " Time of injury: [00:00 - 05:59] (0.9%), [06:00 - 11:59] (9.3%), [12:00 - 17:59] (63.6%), [18:00 - 23:59] (23.5%), unknown (2.8%). Only data on time of injury, and trail/park were provided with no comparison to frequentation data, so descriptive only. No OR or RR.

OR:	Odds ratio
aOR:	Adjusted odds ratio
IPR:	Injury proportion ratio
XC:	Cross-country
DH:	Downhill
DS:	Dual slalom
MTB:	Mountain biking
MTBikers:	Mountain bikers

SECTION II: GREY LITERATURE REVIEW

Aim

A search of grey literature (i.e. government agency documentation from comparative countries such as Canada, Australia, Wales, Scotland, England, and USA as well as New Zealand) was conducted in additional to the peer-reviewed journal literature, with the aim of identifying other comparative injury prevention frameworks for mountain biking.

Methods

The search of grey literature was conducted in three steps:

1. Identification of institutional websites (cycling federations, mountain biking associations, mountain biking parks) for New Zealand, Canada, Australia, Wales, Scotland, England, and USA.
2. Search on Google using keywords mountain biking AND (injury prevention OR injury risks OR safety)
3. Search of sources cited by the previously identified webpages, and the peer-reviewed articles for which the full-texts were analysed.

Results

Recreational mountain biking injuries were not well documented in the grey literature. However, Table 2 shows that information from web sites did provide information on trail difficulty rating systems (International and country specific or adaptations of the international system), injury prevention initiatives (mostly education courses on safety and bicycle maintenance), and other resources (mountain biking maps of the world).

Table 2. Mountain biking relevant web sites categorized by trail difficulty rating systems, injury prevention initiatives, and other sources.

Source	Link	Country	Year	Description
Trail difficulty rating systems				
IMBA Australia - Australian rating	http://www.ccmbc.com.au/uploads/kentishlatrobe/IMBA_Australia_Trail_Difficulty_Rating_System-July_2012.pdf	Australia	2012	Detailed description of the IMBA system - used in Australia.
Tyrol resort, Austria[16]	http://www.tyrol.com/	Austria		Mountain Bike Model Tyrol Trail Difficulty Rating and Waymarking System.
IMBA Canada	https://cyclingbc.net/	Canada	2014	IMBA system.
International Mountain Bicycling Association (IMBA)[17]	https://www.imba.com/resources/maps/trail-difficulty-ratings	International		Trail Difficulty Rating System (TDRS).
NZ Department of Conservation (DOC)[18]	http://www.doc.govt.nz/parks-and-recreation/things-to-do/mountain-biking/track-grades/	New Zealand		Rating system used by the NZ Department of Conservation - inspired by the IMBA and Kennett Brothers'.
Kennett Bros	http://www.mountainbike.co.nz/politics/articles/grading.htm	New Zealand	1995	Description of the Kennett Brothers rating system.
Woodhill Bike Park NZ	http://www.bikeparks.co.nz/safety	New Zealand	2017	Additional on-trail signage.
The British Cycling Federation[19]	https://www.britishcycling.org.uk/knowledge/training/article/izn20130802-Mountain-bike-trail-centre-grades-0	United Kingdom		Description of the British system (not IMBA) - Used in England, Scotland.
Wales mountain biking	http://www.breconbeacons.org/mountain-bike-route-grading	Wales		Presentation of the system used in Wales - similar to the UK + 1 level.
Injury prevention initiatives				
Mountain bike Australia[20]	https://www.mtba.asn.au/news/first-aid-for-mountain-bikers/	Australia	2015	First aid course for mountain bikers.

CAN-BIKE[21]	http://canbikecanada.ca	Canada	Learn to ride safely (mostly on road).
Let's ride[22]	http://www.cyclingcanada.ca/resources/lets-ride/	Canada	Program to develop basic cycling skills to youth at the community level (mostly on road).
Vancouver Coastal Health - Shred safe[23]	http://www.vch.ca/about-us/news/shred-safe-dont-let-injury-cut-your-mountain-biking-season-short	Canada	MTB safety contest from the Vancouver health care system (Whistler region) - Photo contest to win coaching lessons and protective gear.
Various - not MTB specific		Canada	Parachute, Preventable, No regret, …
Sprockids[24]	http://sprockids.com/	International	Courses for MTB education for kids and teenagers (skills, bike maintenance, environment, trail safety).
We are Cycling UK	http://www.cyclinguk.org/cycling-advice	United Kingdom	Courses to be a cycling leader, first aid, bike maintenance.
British cycling[19]	https://www.britishcycling.org.uk/search?s=injury+prevention	United Kingdom	Several training and strengthening plans and advices for cyclists.
Auckland Transport	https://at.govt.nz/cycling-walking/training-and-events/bike-care-and-maintenance/	New Zealand	Bike maintenance.
Other resources			
	https://www.trailforks.com	International	All MTB trails in the world, by region, with length, difficulty rating.

Trail rating systems

Mountain biking trails are usually rated with respect to their difficulty to help riders find tracks according to their own ability. The matching of ability and trail difficulty is likely an important risk factor for injuries. The rating system started as a variation of the widely used rating of snow skiing trails.

Most countries with mountain biking parks use systems based on the same elements (trail dimensions, surface, elevation changes, technical features) and the same coding (black as the most advanced grade), although a few differences exist in the number of difficulty levels and the associated colours (see Figure 2. IMBA Trail Difficulty Rating System, used in the USA, Canada and Australia (source: imba.com).

and **Error! Reference source not found.**).

Figure 2. IMBA Trail Difficulty Rating System, used in the USA, Canada and Australia (source: imba.com).

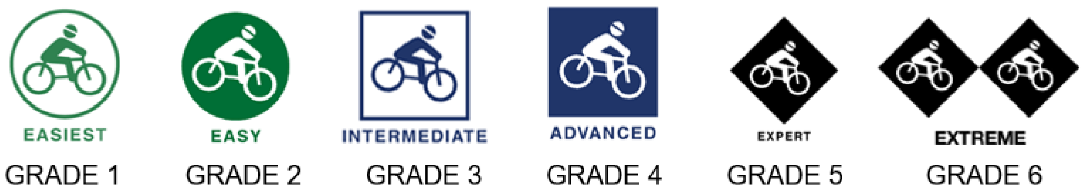

Figure 3. Department of Conservation mountain biking track grades, New Zealand (source: www.doc.govt.nz).

The International Mountain Biking Association (IMBA) Trail Difficulty Rating System (TDRS)[17] uses both objective and subjective qualities of a trail. The technical challenge is assessed by measurable parameters: minimum trail width, trail surface, maximum and average trail gradient, natural obstacles and technical trail features (height of unavailable obstacles, loose rocks, bridges). In addition, the perceived difficulty of the trail is also evaluated, and varies according to the psychological challenge (exposure, corridor clearance, turn radius for example). In that perspective, these elements should be mentioned in the description of a track. IMBA administrators also recommended indicating the trail length and elevation change in order to rate the physical exertion, which will directly depend on the rider's ability.

In New Zealand, the Department of Conservation (DOC) uses a rating system inspired by the Kennett Brothers' system (experienced mountain bikers in NZ, publishers of several biking guides, in collaboration with NZMBA) going from Grade 1 (the easiest, white circle) to Grade 6 (double black diamond).[18] The Kennett Brother's system is based on an overall grade (track surface, length, challenges) and a maximum grade (on the hardest rideable section: slope, turning radius, potential fall height and risk of injury). The maximum grade is in brackets and +/- can be added for nuance (example: Grade 2+ (5)). The system mentions that the ride will be harder if it has been raining/is raining. DOC is using a variation of the IMBA coding with similar symbol colours and shapes.

In opposition to the IMBA TDRS, the British system is based on distance and elevation as well as technical difficulty.[25] In order of increasing difficulty: Green, Blue, Red, Black. Additionally, Orange indicates bike parks with downhill runs. Wales has an additional, easier, Yellow grade.[26] Austria seems to have its own code: in order of increasing difficulty: Blue, Red, Black, Yellow.[16]

This variety of rating systems internationally is likely to lead to misinterpretation by riders traveling between countries. Therefore, common tourist destinations need to ensure there is clear signage that outlines the interpretation of the grading systems.

The IMBA also recommends that the trails should be rated relative to other trails in the region. "Trails will rate differently from region to region. A black diamond trail in one region may rate as a blue square in another region, but the ratings should be consistent locally." A 'Very difficult' trail in a given region could be equivalent to an 'Easy' trail in another region, depending on what it has to offer. However, a criticism of this system is that it may lead to unexpected difficulty when a mountain biker starts riding in an unknown region.

Although it does not seem to be common practice, some mountain riding parks have signage along trails to warn about obstacles or technical difficulties (**Error! Reference source not found.**).

Figure 4. Signage on the Woodhill mountain bike park trail, New Zealand (source: http://www.bikeparks.co.nz/safety).

Rating systems differ in their criteria, especially in regards to the psychological challenge offered by a trail. According to Siebert et al.[27] dangers surrounding the trail itself are analysed differently by mountain bikers' depending on their experience: beginners focus longer on danger areas than experts, who focus longer on the trail itself and its technical features. This means that the bikers' attention, especially if beginners, is not solely focused on physical trail criteria, in opposition to some rating systems. The presence of danger areas might furthermore be associated with a rise in anxiety for novice mountain bikers. A rise in anxiety has been shown to lead to a decrease in visual attention towards important parameters, and of performance and control in driving situations.[27]

Other studies on mountain bikers have revealed that experience influences risk perception and affective outcomes[28] and that the more experience, the more desire for challenge, excitement and speed.[29]

The conclusion from these studies is that the rating of mountain biking trails requires information on technical challenges as well as potential dangers and perceived risk. To help beginners and experts, it is recommended that these two aspects be described separately as both groups interpret them differently. This also raises the question of who should evaluate the perceived risk as experienced bikers might ignore some psychological features that beginners would otherwise consider.

Injury prevention initiatives
Some safety initiatives were identified from national or regional associations websites (e.g. www.britishcycling.org.uk) and were categorised as:

- *Learn to bike*: Practical courses to develop cycling skills and confidence from basic to expert level, to kids and adults. Most courses are focused on on-road training, with a few on mountain biking, and some others provided by the mountain biking parks.[21, 22, 30, 24] Some courses are intended for people wanting to become cycling coaches.
- *First aid courses:* Mountain biking or cycling specific first aid courses.[20, 30]
- *Bike maintenance:* Courses on basic bike maintenance.[30, 24]
- *Photo contest:* Vancouver Health Care centre has offered a photography contest to mountain bikers, along with the promotion of the results of a study performed in their region.[31] Prizes were mountain biking coaching lessons and protective gear.[23]
- *Training and strengthening*: Advice and example workouts for cyclists, mainly on core and leg strength.[19]

SECTION III: HADDON MATRIX EVALUATION

Aim
To summarise the information from the peer-review journal material and the grey literature material.

Background
In order to implement effective injury prevention preventative measures, the initial phases of sports injury prevention aim to establish the extent of the problem and identify the aetiology and mechanisms of injury.[32] The events leading to mountain biking injuries, the types of injuries, and potential countermeasures (strategies) all need to be understood.

Methods
A Haddon's matrix[3] conceptual framework for injury causation (host/mountain bike participant, agent/mechanism and environment/community) was used to extract themes and create evidence summaries from the peer-review journal material.

Results
There were no randomised control trials to provide evidence from the scientific literature for effective injury prevention countermeasures targeted at mountain biking risk factors.

Table 3 provides the summary of host/participant, agent/mechanism and environment/community mountain bike risk factors in column 1, evidence for risk factors from studies in column 2, and relevant extracted theme in column 3. The key themes extracted from the journal literature and grey literature included physiological factors, biker skill related factors, psychological factors, safety gear related factors, bicycle technical related factors, trail factors.

Table 3. Summary of host/participant, agent/mechanism and environment/community mountain bike risk factors.

Host/participant	Evidence	Theme
General health		
Age[a,d]	Age[11]	Physiological
Sex[a,d]	Sex[11]; Women versus men[7, 2]	Physiological
History of injury[c,d]		

Body – motor control		
Physical condition[c]		
Duration of warm-up before the first ride[c]		
Weight[c]		
Body composition[c]		
Nutrition and hydration[c]		
Fitness/fatigue[a]	Fatigue[15, 6]	Physiological
Vision/sight[a]	Poor sight[6]	Physiological
Psychomotor skill development[a]	Loss of control[10, 9, 12]; Riding errors[6] Loss of traction[10]	Biker skill
Biomechanical skill development[a]	Jumping[1]; Jump or trick[12, 8]	Biker skill
Ability/experience		
Seasons of experience in mountain biking[a]	More off-road hours each week[14]; More total hours each week[14]	Biker skill
Self-reported ability (beginner intermediate, expert)[a]	Competitive activity level[9]; Pro versus amateurs[2]; Experts versus professionals[6]; Riding beyond one's ability [14]	Biker skill
Behaviour		
Readiness for speed[a]	Excessive speed [15, 14, 1]; High-speed descent[9]	Biker skill
Risk taking behaviour; judgment & recklessness[a]	False judgement of situation[15]; Inattentiveness[14]	Psychological
Abstinence from alcohol[a]/alcohol intoxication[a]	Intoxication - alcohol or marijuana[14]	Psychological
Abstinence from drugs[c]		
Readiness for risk[c]		
Use of appropriate equipment[c]		
Lessons[a]	Instructional course for beginners[6]	Other factor
Knowledge		
Knowledge about mountain biking safety and injury mechanisms[c]		
Knowledge of trail details & safety rules[c]		
Knowledge of injury prevention strategies[c]		
Agent/mechanism		
Behaviour		
Protector use (e.g. wrist brace, knee brace)[a]	Wearing more protection[1]	Safety gear
Wrist guard worn[a]	Wrist guards[8]	Safety gear
Helmet worn[a]	Helmet[13, 7, 8]	Safety gear
Gloves worn[a]	Gloves protective[7]	Safety gear
Limb body armour worn[a]	Limb body armour protective[7, 8]	Safety gear
Equipment ownership[c]		
Seasonal checking of equipment by specialist[c]		
Recreational versus competitive[a]	Competition versus practice[6]	Other factor
Injury and treatment		
Effectiveness of treatment[a]		
Severity of injury[a,d]	Severity of injury[1]	Other factor
Protectors		
Equipment design[a]	Wrong choice of materials[6]	Bicycle technical
Age of equipment[a]	New bicycle (ridden less than 10 times)[1]	Bicycle technical
Equipment mechanical problem[a]	Mechanical problem[10]; Technical failure[6, 15]	Bicycle technical
Environment/community		
Behaviour		
Proximity to other participants[c]		
Experience of aggressive behaviour of other participants[c]		
Injury and treatment		

First-aid[c]	Reduce time between injury and treatment[13]	Other factor
Help-seeking behaviour[c]		
Access/transport to hospital care[c]		
Quality/affordability of health care[c]		
Weather and terrain		
Weather[a]	Weather[6, 14]	Trail
Trail conditions (hard, soft, muddy)[a]	Poor trail conditions[6]; Slippery terrain[15]	Trail
Trail grade (black, orange etc)[a]	Trail grading difficulty[7];	Trail
Trail slope (downhill, level, uphill)[a]	Downhill[10, 8, 14]; Uphill riding[9]; Biking on level[8]	Trail
Accessibility to trails (region)[a]	Unfamiliar terrain[14]	Trail
Trail bans or access (barriers, signage)[c]		
Trail grooming[a]	Unforeseen trail obstacle[6]; Terrain ridden - dirt more than rocks, sand or paved[14]; Paved terrain than off road[14];Frequent inspection of trail for obstacles[6]	Trail
Trail planning/composition[a]	Collision with tree[13]; Collision with object[10]; Collision with rider[10, 6]; Collisions with other bikers, cars or animals[15, 12];Strict separation of hiking and downhill trails[6]	Trail
Temperature[c]		
Protectors		
Protective barriers/mats[c]		Safety gear
Noise[c]		Safety gear

[a]Factors derived from literature
[b]Factors included in intervention studies (No studies in this review)
[c]Factors not yet addressed in studies
[d]Unalterable factors.

Discussion

The scoping review of peer-reviewed and grey literature aimed to provide evidence from journal and grey (web documents) literature of the risk factors and effectiveness of injury prevention countermeasures for mountain biking. As no studies were found that evaluated the effectiveness of injury prevention strategies via controlled interventions the inclusion criteria were adapted and included qualitative papers to build context around the subject. Twelve studies were included in the qualitative synthesis. Findings from the peer-reviewed academic literature were combined with information obtained from a grey literature search of mountain bike association documentation publically available globally. This information was categorised using the Haddon's matrix conceptual framework, with the overall findings are discussed in more detail in the following section.

Aetiology of mountain biking injuries

Injury patterns associated with mountain biking are known.[7] Mountain bikers sustain upper extremity injuries, particularly shoulder injuries (clavicle fractures are the predominant injury, and acromio-clavicular dislocations are frequent) and fractures and joint injuries of the upper extremity (elbow, wrist, hand and fingers).[33]

Injury rates for recreational mountain biking have been reported as 1.54 injuries per 1000 biker exposures using data from a prospective study at care facilities (first aid station to trauma centre) over one year in Scotland.[7] The injury rate was higher in men (1.64 per 1000 biker exposures) than in women (1.08), with those aged 30-39 years at highest risk. Common injury types were wounds, skeletal fracture, musculoskeletal soft tissue injury and joint dislocations. Limbs were more commonly injured than the axial skeleton, however, the highest hospital admission rates were for head, neck and torso injuries.

Physiological factors

There was some evidence for physiological factors (age,[11] sex,[11] women versus men,[7, 2] fatigue,[15, 6] poor sight,[6]) having an effect on mountain biking injuries. It is not clear if males are more likely to be injured than females given studies[11, 7, 2] presented injury frequency and not injury rates taking into account exposure. It is worth noting that women more easily attributed their accidents to overexertion compared to men, suggesting limited strength and endurance.[33] One study in the United States[11] did report injury proportion ratios with males sustaining more dislocations (IPR, 1.9; 95% CI, 1.1 to 3.4), more shoulder injuries (IPR, 1.9; 95% CI, 1.6 to 2.3), and fewer lower-extremity injuries (IPR, 1.3; 95% CI, 1.0 to 1.6) than females. However, females were more frequently hospitalized (IPR, 1.4; 95% CI, 1.1 to 1.7).

<u>*Recommendation/considerations for countermeasures*</u>
For physiological factors, interventions that focus on muscular strength and endurance to reduce arm and leg fatigue, and to improve better decision-making, may help reduce the risk of injury; however, intervention studies are needed to confirm the effectiveness. Increased strength and endurance, specifically of the upper body and core, could improve the cyclist's control over the bike, as well as preventing them letting go of, and being thrown over, the handlebars.[33, 15] However, intervention studies are needed to confirm the effectiveness.

Biker skill related
Bike skill related factors included psychomotor skill development (loss of control,[10, 9, 12] riding errors,[6] loss of traction[10]), biomechanical skill development (jumping,[1] jump or trick[12, 8]), ability and experience (more off-road hours each week,[14] more total hours each week[14]), self-reported ability (competitive activity level,[9] pro versus amateurs,[2] experts versus professionals,[6] riding beyond one's ability[14]), and readiness for speed (excessive speed,[15, 14, 1] high-speed descent[9]).

Beginners may be more at risk of injury having less specific strength, coordination and skill than more experienced mountain bikers. However, it seems that there were more injuries in the more experienced and competitive mountain bikers. For example:[15] "Participants in races did not show a higher injury rates than non-competitors"; "Experienced athletes' higher incidence of joint and bone injuries than first year beginners"; "There was no significant difference in the injury rate between beginners and athletes experienced more than four years"; "Self-induced injuries affected beginners and experienced athletes to a similar rate of approximately 75% each."

It was not clear from the literature whether the risks in downhill mountain biking were the same as other types of mountain biking. As the skills required for downhill differ for those required for trail riding, differentiation within the literature in risk factors across mountain biking disciplines is needed.

There were differences between recreational and competitive cohorts (competitive activity level,[9] pro versus amateurs,[2] experts versus professionals[6]) suggesting that interventions need to be focused on specific mountain biking groups. For example, in a study of downhill mountain biking,[6] experts had 17.9 injuries per 1000 h of exposure, which was significantly higher than the 13.4 for professional riders (OR 1.34; 95% CI, 1.02 to 1.75; p=0.03). As there was a significantly higher rate of injury reported during competition (20 per 1000 h) than during practice (13 per 1000 h) (OR 1.53; 95% CI, 1.16 to 2.01; p=0.0022), specific interventions for competitions are also to be considered. Several studies [13] [15] that reported epidemiology data did not report risk factors separately for competitive versus recreational mountain biking.

<u>*Recommendation/considerations for countermeasures*</u>
For biker skill related factors, interventions that focus on teaching mountain bikers how to keep control of the bike under a variety of conditions including downhill, and how to ride within their ability, including not having excessive speed, may help reduce the risk of injury.

Psychological factors
Psychological factors that may increase injury risk included risk taking behaviour and poor judgment and recklessness (false judgement of situation,[15] inattentiveness[14]) and use of alcohol and drugs (intoxication - alcohol or marijuana[14]).

The situation leading to 34% of injuries included false judgement of situation[15] in a retrospective, questionnaire-based survey in Germany, Austria, and Switzerland. An injury sustained in mountain biking (recreational and competition) was defined as one preventing the practice of mountain biking for at least one day.

Factors contributing to accident, as declared by participants included inattentiveness (23%), and intoxication - alcohol or marijuana (2.6%) in a retrospective, questionnaire-based survey in the United States of America. The question was "What is the most recent injury sustained while off-road biking defined as the presence of pain, discomfort, or disability, and rated in severity according to required treatment.[14]

Recommendation/considerations for countermeasures
For psychological factors, interventions that focus on improvement of judgement skills, improving attentiveness to signs, trail conditions and obstacles, and reducing alcohol and drug use, may help reduce the risk of injury.

Safety gear related factors
Safety gear/protector use related factors (wearing more protection[1]) included helmets,[13, 7, 8] wrist guards,[8] gloves[7] and limb body armour.[7, 8] For example, in a study[7] of recreational mountain biking injuries in Scotland, protective body armour, clip-in pedals and the use of a full-suspension bicycle seemed to confer a protective effect.

Helmets may be beneficial for reducing risk of head injuries in mountain bikers and possibly useful in the reduction of neck and other injuries. In a study[4] with only 14 mountain bike head injuries, helmets were considered to be effective in decreasing the risk of head injury in off-road cycling crashes (OR for head injury in helmeted vs un-helmeted cyclists = 0.39, 95% CI, 0.10 to 0.65). However, there was no statistically significant difference in injury severity scores between helmet-compliant and helmet-noncompliant riders in a retrospective study conducted at a trauma center (referral for spinal cord injuries), between 1955 and 2007 in Canada.[13] Information is needed on the protective effects for types of helmets given the use of full face versus open face helmets, and the types of mountain biking. Downhill mountain bikers often use full face helmets with body armour given the perceived, and actual, increased risk of injury.

There is a large variety of mountain biking protective gear available (**Error! Reference source not found.**.)[34] including knee pads and elbow pads, eye protection (goggles), full face helmets, chest and shoulder protective tops (body armour), padded shorts etc.

Figure 5. Signage on the Woodhill mountain bike park trail, New Zealand (source: http://www.allsportprotection.com/Mountain_Bike_Protective_Gear_s/4.htm).[34]

Recommendation/considerations for countermeasures
For safety gear/protector use related factors, interventions that focus on strongly encouraged use of mountain biking protective gear (e.g. limb body armour) may help reduce the risk of injury.

Free protective gear could be available for mountain bikers to use. This would encourage those willing to utilise protective gear to do so. A try-to-buy scheme could be trialled where hire of safety gear could be taken off the purchase price of the gear after the initial trial.

Bicycle technical related factors
Bicycle technical related factors included equipment design (wrong choice of materials[6]), age of equipment (new bicycle - ridden less than 10 times[1]), and equipment mechanical problems (mechanical problem,[10] technical failure[6, 15]).

The use of rented, new, or badly maintained equipment[1] may be harmful, however, it was not always clear from the studies whether it was the equipment per se, it's maintenance, or the people who used it that resulted in equipment being a risk factor. Equipment failure can lead to 6 to 16% of injuries (flat tires, brakes, chains, forks, handlebars, pedals, cranks, suspensions).[33] Correct bicycle size to fit the participant's height, and correct maintenance of bicycles to ensure correct tyre pressure to avoid sliding out, or seat height to avoid the participants centre of gravity being too far forward, resulting in increased risk of going over the handle bars, are some potential issues.

Recommendation/considerations for countermeasures

For bicycle technical related factors, interventions that focus on maintenance of bicycles, and correct fit of the bicycle for the ability of the mountain biker may help reduce the risk of injury.

Trail grade/conditions factors

Trail factors included weather conditions affecting the trail (weather[6, 14]), trail environmental conditions (poor trail conditions,[6] trail grading difficulty,[7] downhill riding,[10, 8, 14] uphill riding,[9] biking on level,[8] unfamiliar terrain,[14] terrain ridden - dirt more than rocks, sand or paved,[14] paved terrain than off road[14]) and biker/trail interaction conditions resulting in collisions (collision with tree,[13] collision with object,[10] collision with rider,[10, 6] collisions with other bikers, cars or animals,[15, 12] separation of hiking and downhill trails,[6] unforeseen trail obstacle,[6] frequent inspection of trail for obstacles[6]).

Inclement weather may be harmful if it causes an increase in trail slipperiness, increasing the risk of injury. Weather conditions were involved in 8% of accidents in the prospective study, with monthly e-mail based surveys in 2011, in Germany, Luxembourg, Switzerland and Austria.[6] The circumstances of incidents included sliding (16%), front wheel sliding (12%), side slipping (10%), and slipped of the pedal (12%). While this study provides data from European countries with snow, the relevance to NZ is the cause of sliding or slipping which can also be induced in NZ conditions with wet conditions or trail composition.

Visibility of signage and obstacles appear to be key factors contributing to increased risk of injury. Increasing the size and frequency of signage to improve visibility during inclement weather periods may help decrease injury incidence. For example, the average reaction time, from the time a sign comes into view to respond to avoid an obstacle, is 1 s in clear visibility for skiing, therefore during adverse weather conditions there is a need to allow greater times for reacting to signage before obstacles.[35] This type of information is helpful in determining how far signage should be from obstacles in mountain biking.

Falling over the handlebars is the most common injury mechanism (involved in about 75% of accidents), and typically occurs when the front wheel hits an obstacle.[6] Obstacle presence and disposition should be arranged to ensure that they are ridable by riders of the targeted ability. Trails need to be groomed and well maintained to avoid undesirable obstacles (fallen branches, deep holes or high roots). Poor trail conditions (31%) and unforeseen obstacles (16%) were involved in downhill mountain biking injuries.[6] Other risk factors such as jump planning and trail grading need further investigations using epidemiology risk factor analyses so that odds ratios can be determined. Experimental studies in skiing have indicated that design of the landing surface is important for reducing injury risk[36, 37] and therefore could be considered in mountain biking.

Some authors[38, 15, 31] mentioned that geographical origin of the injured mountain bikers could be an injury risk, however, there was no analysis to determine if geographical origin was a risk factor.

Recommendation/considerations for countermeasures

For trail related factors, interventions that focus on good trail environmental conditions, and reduction of potential obstacles such as other riders and non-riders, may help reduce the risk of injury. The rating of mountain biking trails requires information on technical challenges as well as potential dangers and perceived risk. To help beginners and experts, it is recommended that these two aspects are described separately as both groups interpret them differently. This also raises the question of who should evaluate the perceived risk as experienced bikers might ignore some psychological features that beginners would otherwise consider. Another potential effective counter measure is instructional courses for beginners.

The design of the mountain bike trails should be considered. Filtering systems could be developed where more challenging obstacles (e.g. a hard jump) are placed at the start of a mountain bike trail to filter out those without the necessary skill to use the trail. Alternative routes should be designed to offer the riders the possibility to avoid a challenging obstacle – which is considered good practice in New Zealand mountain biking parks already.

Regular checks of trails should be conducted to ensure there are no adverse items that could cause unintentional collisions or falls. For example, checking the status of the trail for damage or obstacles (e.g. fallen tree/gouged out parts of the track/large rocks that have fallen into the trail).

Consider increasing the size and frequency of on-trail signage to highlight technically difficult parts of trails (jumps, sharp turns, slopes, slippery terrain such as loose gravel), especially if they are unforeseeable, such as after a turn. The average reaction time from the time a sign comes into view to respond to avoid an obstacle is ~1 second in clear visibility, therefore in adverse weather conditions or in parks with limited long range visibility there needs to be allowance for greater times for reacting to signage before obstacles

Information from mountain biking relevant web sites resulted in themes of trail difficulty rating systems, and injury prevention initiatives. The variety of rating systems internationally is likely to lead to misinterpretation by riders traveling between countries. Therefore, common tourist destinations need to ensure there is clear and consistent signage and in alignment with international standards/systems (e.g. Kennett Brothers system used by the IMBA that has been adapted for used by the NZ Department of Conservation) that outlines the interpretation of the grading systems. A trail/track standard for New Zealand (e.g. adoption of IMBA standard) should be considered.

Other factors
Other injury risk factors included competition versus practice[6] and severity of injury.[1] For example, riders who self-reported cycling faster than usual had significantly higher risk of severe injury compared with others.[1] The risk of severe injury may be reduced by encouraging bicyclists to control their speed or by modifying mountain biking park design to limit the opportunity to gain speed.

Countermeasures development
There was no clear evidence for effectiveness of injury prevention countermeasures from intervention studies or studies evaluating cost to benefit ratio of countermeasure interventions, suggesting further research is required in this area.

In light of the dynamic, recursive model of aetiology in sport injury,[39] preventive countermeasures for mountain biking injuries should focus on identifying and limiting risk factors. Examples of potential extrinsic factors include legislation (e.g. mandatory helmet use),[40] and equipment (e.g. protective body armour, clip-in pedals, full-suspension bicycles.[7, 8] Inalterable intrinsic factors, such as injury history, age[11] and sex,[11, 7, 2] have been proposed and are currently being studied. Strength and neuro-muscular control could be useful for injury prevention given opportunity for training and conditioning as successful means of injury prevention in other sports.

Given the lack of clear evidence available from the mountain biking literature examples for consideration as countermeasures were derived from the findings within the mountain biking epidemiology based literature, and evidence of effectiveness of countermeasures in other sports such as snowsports[41] that has similar risk factors (e.g. risk taking behaviour of participants, high speed, downhill, trail navigation tasks, trail conditions, use of protective wear, equipment design).

Specific solutions for countermeasure intervention should be developed in collaboration with personnel at mountain bike parks and experienced mountain bikers. When designing countermeasures, the “E's of injury prevention”[42] including environment, enforcement (of legislation and policies), education, engineering, should be applied to mountain biking injury prevention.

Enforcement (of legislation and policies)
There are currently no national policies for mountain biking that can be enforced. It is suggested that a new national trail standard could be considered adapting international examples.

Engineering
Technology and equipment changes may result in different effect sizes for injury risk. Therefore, an implementation

plan for countermeasure interventions for mountain bikers needs to consider the current socio-cultural and technological context.

Rental bikes should be well maintained to prevent equipment failure. Mountain bike parks could offer free checks of owner's bikes (tire pressure, brakes, pedals). Any equipment provided by the park should be of high quality and appropriate for the type of mountain biking offered by the park (e.g. hard-tail vs full suspension).

Environment

Improvement to the mountain biking environment via signage to enable better match of ability and terrain by mountain bikers, terrain condition improvement, daily grooming and appropriate rating of trails, on-trail signage to warn about obstacle and danger zones and potentially bypass routes, should all be considered.

Education

The effectiveness of education interventions was unclear based on the studies identified. A potential effective counter measure is instructional course for beginners.[6] Educational courses on technique and skills, equipment and awareness of hazards, both to avoid mistakes[6] and to enable proper trail selection[33] have been conducted for mountain biking. However, well designed studies to assess the effectiveness of education interventions have not been investigated.

Based on experiences with other sports such as snowsports,[41] interventions for consideration are: educational videos are targeted at particular sub groups of mountain bikers. Workshops could be developed for more experienced mountain bikers, using videos of injurious or near injurious events to promote thought and discussion of key factors to be aware of and how to respond to different potentially injurious situations. Given dangers surrounding trails are analysed differently by mountain bikers' depending on their experience (beginners focus longer on danger areas than experts, who focus longer on the trail itself and its technical features)[28] different workshop material will be needed for experts than beginners.

Lesson instructors should be encouraged to remind mountain bikers to gradually challenge themselves with their newly acquired skills. Beginner participants should be encouraged to build up speed and technical aspects slowly. The risks of downhill and going over the handlebars needs to be highlighted, with education on technical strategies for bike control provided. Education material and workshops on how to fall off a mountain bike safely should be developed.

Digital assets such as cell phones, web sites and TV screens mounted at mountain biking parks and facilities could be used to provide injury prevention messages. Display examples of signage for hazards on the trails.

Target information to equipment renters regarding protective gear (e.g. body armour), appropriate bicycle size fitting, awareness and key injury prevention skills. Possible options could include compulsory reading of information before equipment is provided, free body protectors, and educational videos at rental facilities.

CONCLUSIONS

The scoping review of peer-reviewed and grey literature, with analyses using a Haddon's matrix conceptual framework for injury causation, identified a number of recreational (general public use of bike parks, not racing) mountain biking injury risk factors that may be addressed by injury prevention strategies. However, further research with intervention studies are needed to confirm the effectiveness of countermeasures.

Key risk factors to focus on for injury prevention interventions that may help reduce the risk of injury include:

- **Physiological factors** - muscular strength and endurance to reduce arm and leg fatigue, and to improve better decision making.
- **Biker skill related factors** - teaching mountain bikers how to keep control of the bike under a variety of conditions including downhill, and how to ride within their ability, including not having excessive speed.
- **Psychological factors** - improvement of judgement skills, improving attentiveness to signs, trail conditions and obstacles, and reducing alcohol and drug use.
- **Safety gear/protector use related factors** - strongly encouraged use of body armour.
- **Bicycle technical related factors** - maintenance of bicycles, and correct fit of the bicycle for the ability of the mountain biker.
- **Trail related factors** - good trail environmental conditions, and reduction of potential obstacles such as other riders and non-riders.

Countermeasures that might be effective based on other sport interventions (given there were no mountain biking specific interventions) and the E's of injury prevention could include:

- **Enforcement** of a new national trail standard;
- **Engineering** by provision of protective gear including body armour to reduce shoulder/clavicle injuries, rental and visitors' bikes maintenance;
- **Environment** via signage to enable better match of ability and terrain by mountain bikers, terrain condition improvement, daily grooming and appropriate rating of trails, on-trail signage to warn about obstacle and danger zones and potentially bypass routes;
- **Education** for mountain bikers on risk factors and their countermeasures such as equipment maintenance information, and education sessions for beginners on risk-taking behaviour ("riding beyond one's ability": excessive speed, jumps, riding inadequate trails) and learning appropriate mountain biking techniques (braking, cornering, jumping); body armour with shoulder protection recommended for advanced riders.

APPENDIX 1 - METHODOLOGY, TIMELINES, KEY MILESTONES AND DELIVERABLES

An approach was taken to enable the identification of risk factors and quantification of evidence for effectiveness of injury prevention countermeasures for mountain biking. A literature scope, rather a full review, was conducted to determine:

1) what literature resources exist around the project
2) the type of study designs in the published literature
3) the main themes from the studies.
4) a comprehensive search strategy
5) evidence tables (but NOT a critical appraisal) grouped by themes that come out of the peer-reviewed academic literature
6) Search of grey literature in the form of guidance from other government documentation and relative industry bodies.

The methodological approach involved:

- **Developing a finalised search strategy** that was sent to ACC for approval by the Research team and the Injury Prevention team;
- **Identifying relative evidence with the search strategy using databases** that included Medline, Pre-Medline, Trip database, Embase, PubMed, Cochrane Library and Google Scholar for peer-reviewed literature;
- **Grey literature** searches including a systematic search of other government agency documentation from comparative countries that may include comparative injury prevention frameworks in Canada, Australia, Wales, Scotland, England, and USA.
- **Selection of the evidence for inclusion in the review**:
  Inclusion criteria:
  - Search terms included: Downhill mountain biking, Enduro, single track biking, cross country and recreational mountain biking

  Study designs:
  - Systematic reviews
  - Primary studies: may include prospective and retrospective cohort, analyses of administrative data,
  - Grey literature (including relevant guidelines and government reports)

  Exclusion criteria:
  - Non-English studies
  - Commentaries and opinion pieces
- **Findings were summarised as key themes** determined on findings within the literature. This was done in collaboration with ACC.
- **Evidence statements** outlining the number of each study type found for the themes was completed.
- **Possible key risk factors for mountain biking injuries** were outlined that can be evaluated for evidence of effectiveness of existing injury prevention countermeasures in recreational (general public use of mountain bike parks, not racing) mountain biking using a Haddon's matrix conceptual framework for injury causation (host/ mountain biking participant, agent/mechanism and environment/community).
- The **strength of the** evidence for effectiveness of injury prevention countermeasures in mountain biking would be the aim of a full final review, based on direction from the scoping literature review.

Patria, Enora, Melissa and Kirsten worked together with weekly email updates to deliver the project milestones and deliverables to ACC according to the timeline in the contract. The contract between AUT and ACC was formally signed on 20/02/2017 (after the initial contract dates indicated we would start). An extension was given by ACC for the final report given the work commitments of all parties. The budget was fully expended as per the contracted budget.

Deliverable	Due date	Completion date
Agreed search strategy, project plan and indicative evidence table structure.	7 February 2017	3 February 2017
1st draft of reference list of peer-reviewed literature and grey literature. Presented in an excel workbook using pivot table function. Work sheets separated into "included", grey literature" and "to be determined". Worksheets will include a brief description of paper; the structure will be determined with the search strategy (above). A list of excluded papers to be included in a separate worksheet but reference only is required. To be reviewed and discussed with ACC regarding inclusion / exclusion of final list of papers: *3 day turnover by ACC*	16 February 2017	15 February 2017
2nd draft of reference list with completed reference tables of peer-reviewed literature and grey literature Initial draft of brief report describing findings: *3 day turnover by ACC*	1 March 2017	1 March 2017
Delivery of final report for ACC. Report will include: Objective of report, methodology (including search strategy, inclusion and exclusion criteria) and a summary of literature found, grouped into relevant themes that arose from the literature. A summary statement should also be included on the literature base available for this subject. Tables summarising relevant papers to be included as appendices and grouped by theme: *3 day turnover by ACC*	7 March 2017	7 March 2017
Finalised document with final amendments complete and closedown of project for dissemination	17 March 2017	30 April 2017

APPENDIX 2 - EXCLUDED STUDY DETAILS

List of journal articles with "mountain bik"

There were 254 articles containing the word "mountain bik" that were abstract reviewed.

1. Mountain bikers' injury lingo. Physician Sportsmed. 1999;27(5):22-.
2. Mountain bike injuries -- for men/bike seat tilt reduces low-back pain. Sports Physical Therapy Section. 2000:3-.
3. Study unveils scrotum injuries in mountain bikers. Physician & Sportsmedicine. 2000;28(1):16-.
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5. Spinal Column and Spinal Cord Injuries in Mountain Bikers. American Journal of Sports Medicine. 2010;38(8):1647-52.
6. New national study finds mountain bike-related injuries down 56%. NEWS-Line for Physical Therapists & PT Assistants. 2011;16(3F):7-.
7. Mountain biking is associated with a risk of injury mainly to the upper limbs - protective body armour, clip-in pedals and the use of a full suspension bicycle may provide a protective effect. British Journal of Sports Medicine. 2011;45(13):1081-.
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After abstract review, there were an additional 31 studies initially excluded due to:

6 Language
2 Duplicate
15 No OR or RR
2 Not MTB
3 No full-text
3 Low number of participants

Category	Reference	Title	Reason for exclusion	Description
Competitive	Carmont et al., 2005[43]	The impact of an extreme sports event on a district general hospital.	No OR or RR	Retrospective study, at hospital near and during a MTB racing event. Descriptive only, not relevant.
Competitive	Grooten et al., 1999[44]	Injuries among Swedish mountain bike cyclists at an elite level.	No full-text	Survey of 115 elite Swedish mountain bike cyclists. Mailed self-administered injury history questionnaire. 71 subjects reported 137 minor injuries, mostly striking the knees and lower back. 56 subjects reported 79 major injuries mostly occurring in the knees, hands and feet. The main causes for minor and major injuries were "too much training" and "falls". A tendency was seen that those who train more hours per week, especially during pre-season training, incurred fewer injuries.
Competitive	Kronisch et al., 1996[45]	Acute injuries in off-road bicycle racing.	Low number of participants	Prospective study at a MTB racing event, all injuries while competing, preventing from completing race, N = 16 (11 males, 5 females). Description of type and location, severity of injury, injury mechanisms (mechanical/ lost control/lost traction/collision, Turning/high-speed descent/Starting/jumping, thrown/fell). "Riders who were thrown over their handlebars tended to sustain more serious injuries than those who fell off their bikes to the side (p = 0.03)."
Competitive	Kronisch et al., 1996[46]	Acute injuries in cross-country and downhill off-road bicycle racing .	Low number of participants	Continuation of Kronisch 1996. Prospective study at MTB racing events, downhill and Cross-country, all injuries while competing, preventing from completing race, N = 20 XC, 11 DH. Description of type and location, severity of injury, injury mechanisms (mechanical/ lost control/lost traction/collision). Injury rate higher in DH than in XC (p = 0.01). Injury rate for women compared to men (p = 0.01). Higher severity for being thrown over the handlebars (p = 0.01)
Competitive	Lareau et al., 2011[47]	Injuries in mountain bike racing: frequency of injuries in endurance versus cross country mountain bike races.	Low number of participants	Prospective study, survey-based, for a series of MTB racing events (XC vs. endurance races), all injuries, N = 8 injuries in XC, 17 in endurance. No diff in injury rate between the two types of race. 16% of injuries prevent the rider to complete the race. Descriptive only, no stats.
Competitive	McGrath et al., 2012[48]	Injury and illness in mountain bicycle stage racing: experience from the Transylvania Mountain Bike Epic Race.	No OR or RR	Prospective study at the Transylvania MTB Epic Course (mostly XC, multiday endurance event), all injuries and illnesses, N = 22 injuries. Short description of types of injuries.
Competitive	Meier et al., (2015[49]	Trend sports	Language	In German only.
Competitive	Oehlert et al., 2004[50]	Injuries, training and driving technique of competitive mountain-bikers.	Language	In German only.
Competitive	Pike et al., 2007[51]	Competitive mountain biking injuries in New	No OR or RR	Prospective study at MTB racing events, N = 62 riders for 71 injuries. Descriptive only, not relevant.

		Zealand: 2006 Oceania Nationals.		
General epidemiology	Arnold, 2005[52]	Mountain biking. Cool way to enjoy nature with side effects.	Language	In German only.
General epidemiology	Dannenberg et al., 1996[53]	Predictors of injury among 1638 riders in a recreational long-distance bicycle tour: Cycle Across Maryland.	Not MTB	Prospective study of participants in a 6-day bicycle tour (mostly flat road biking). Analysis of risk ratios.
General epidemiology	Fenzl, 1998[54]	Mountain biking injuries.	Language	In German only.
General epidemiology	Flaherty and Charies, 2008[55]	Mountain biking: An evolving mechanism of injury.	No full-text	Congress abstract only. Retrospective study, MTB patrol/health clinic, N = 467 patients for 592 injuries, competition and recreational MTB.
General epidemiology	Himmelreich et al., 2007[56]	Mountain bike injuries in world-cup and recreational athletes.	Language	In German only.
General epidemiology	BJSM, 2011[57]	Mountain biking is associated with a risk of injury mainly to the upper limbs - protective body armour, clip-in pedals and the use of a full suspension bicycle may provide a protective effect.	Duplicate	Summary of Aitken et al. (2011)
General epidemiology	Ruest et al., 2011[58]	Mountain bike terrain park injuries: an emerging cause of morbidity.	Duplicate	Conference abstract, corresponding article: Romanow 2014.
Other	Harris et al., 2011[59]	The Bicyclists' Injuries and the Cycling Environment study: a protocol to tackle methodological issues facing studies of bicycling safety.	No OR or RR	Presentation of the protocol and methods of investigation. The associated results (Teschke, 2012) only focus on street biking but mentions that downhill grade is positively associated with increased risks (adjusted OR = 2.3; 95% CI = 1.7, 3.1).
Other	Steyn et al., 2014[60]	Classification of mountain bike trails using vehicle-pavement interaction principles.	No OR or RR	Experimental study to assess trail difficulty based on sustained bike accelerations (used to calculate the roughness of the trail), speed, grade, elevation changes and cyclist heart rate. Recommendations on an updated trail grading system. No analysis of injury risk.
Review	Aleman and Meyers, 2010[61]	Mountain biking injuries in children and adolescents.	No OR or RR	Narrative review of the literature, no real focus on children and adolescents, as no study has specifically investigated this population. Review of recommendations for injury prevention, but there hasn't been any intervention study so far.
Review	Carmont, 2008[62]	Mountain biking injuries: a review.	No OR or RR	Narrative review of the literature (2 review articles, 17 case-controlled studies and cross-sectional surveys, 6 case series and 5 case reports). Includes a descriptive table of all references.
Review	Kloss et al., 2006[63]	Trauma injuries sustained by cyclists.	No OR or RR	Narrative review of the literature of cyclists in general, with some data highlighted for MTB and a small focus on facial traumas.
Review	Kronisch, 1998[64]	Mountain biking injuries: fitting treatment to the causes.	No OR or RR	Review of the few articles available in 1998. Summary of traumatic and overuse injuries and potential risk factors. Suggestions of bike fitting adjustments to reduce overuse injuries.
Review	Kronisch and Pfeiffer,	Kronisch, R. L., & Pfeiffer, R. P. (2002).	No OR or RR	Qualitative review of the literature in competitive and recreational MTB, on traumatic injuries. Relatively few

	2002[33]	Mountain biking injuries: an update. Sports Med, 32(8), 523-537.		studies, several case studies. Update of Pfeiffer et al. (1995).
Review	Pfeiffer and Kronisch, 1995[65]	Pfeiffer, R. P., & Kronisch, R. L. (1995). Off-road cycling injuries. An overview. Sports Med, 19(5), 311-325.	No OR or RR	Qualitative review of the literature in competitive and recreational MTB, based on the 5 available studies. Narrative chapter on mechanical evolution of bikes and equipment.
Specific body part	Arnold et al., 1997[66]	The mountain bike: a modern knee destroyer?	Language	In German only.
Specific body part	Bjurlin et al., 2011[67]	Bicycle-related genitourinary injuries.	Not MTB	Genitourinary injuries due to bicycling = 0.07% of all traumas. No specifics on MTB, all types of cycling confounded.
Specific body part	Gassner et al., 1999[68]	Mountain biking–a dangerous sport: comparison with bicycling on oral and maxillofacial trauma.	No OR or RR	Retrospective study at the Department of Oral and Maxillofacial Surgery. Moderate to severe facial trauma, N = 60 mountain bikers. Descriptive comparison of mountain bikers and cyclists, in terms of injury mechanism and detailed type of injury.
Specific body part	Lea et al., 2016[69]	Complex shoulder girdle injuries following mountain bike accidents and a review of the literature.	No OR or RR	Case series study at an emergency department, 2008-2011, UK. Severe specific type of shoulder fractures sustained while bicycling not on a road. N = 5.
Specific body part	Lee and Hsuan-Ju, C. (2007[70]	Facial fractures in mountain biking.	No OR or RR	Retrospective study at the Oral and Maxillofacial surgery unit, Moderate to severe facial trauma, N = 23. Descriptive analysis of facial traumas (age distribution, mechanism of injury, site of fracture, treatment, associated injuries).
Specific body part	Muller et al., 2008[38]	Dental injuries in mountain biking - a survey in Switzerland, Austria, Germany and Italy.	No OR or RR	Cross-sectional, interview-based survey, focus on dental injuries, N = 473 competitive mountain bikers. Descriptive analysis of dental trauma, continuation of activity, awareness of first aid and treatment of injury, mouthguard use.
Specific body part	Rajapakse et al., 1996[71]	Forearm and wrist fractures in mountain bike riders.	No full-text	Full text not found yet.

There were an additional 6 epidemiology references that were excluded.

Category	Reference	Title	Reason for exclusion	Description
General epidemiology	Rivara et al., 1997[4]	Injuries involving off-road cycling.	Use of OR to describe helmet effectiveness, but on a low number of patients (14 MTB head injuries).	Cross-sectional study in hospitals, Moderate to severe injuries sustained while biking (all types of biking, inc. MTB). N = 3390 patients, inc. 127 MTBikers (3.7%). Use of OR to compare MTB to other cyclists. OR for helmet effectiveness (with only 14 MTB head injuries): "Helmets appear to be quite effective in decreasing the risk of head injury in off-road cycling crashes (OR for head injury in helmeted vs unhelmeted cyclists = 0.39, 95% CI, 0.10 to 0.65)."
General epidemiology	Jeys et al.,2001[72]	Mountain biking injuries in rural England...including commentary by Jarvis C.	No OR or RR	Prospective (one year), Orthopaedic trauma unit, mostly recreational and some competitive MTB, N = 84 patients for 133 injuries. Few details on location and type of injury, especially the most serious ones.
General epidemiology	Kim et al., 2006[73]	Mountain biking injuries requiring trauma center admission: a 10-year regional trauma system experience.	No OR or RR	Retrospective study, Trauma center, severe injuries only (requiring at least 3-day admission to the trauma center or ISS >12), Recreational MTB activity taking place in MTB trails or commercial MTB parks. N = 399 patients for 1,092 injuries. Lots of details about type and location of injuries, but only descriptive, nothing on the circumstances of the accident and no analysis on the participants' characteristics. Presentation of Injury prevention measure: TV ad on riding safety (no presentation of results, website dead).
General epidemiology	Ashwell et al., 2012[31]	The epidemiology of mountain bike park injuries at the Whistler Bike Park, British Columbia (BC), Canada.	No OR or RR	Retrospective study, at the Health Clinic close to a major downhill MTB park, Moderate to severe injuries requiring physician care, sustained while riding in the MTB park (extreme sporting events might have been held, but no information). N = 898 patients for 1759 injuries. No control group, descriptive analysis of injuries. "Trails range in difficulty from beginner (17%) to intermediate (23%) to expert (60%)." No data on where the accidents happened. Data on date and time of injury, but no comparison to frequentation data, so descriptive only. Only 0.5% injuries resulted from a collision with another biker, all remaining injuries resulting from falls. This is thought to be due to the fact that all trails are downhill and the lift capacity is limited.
General epidemiology	Kotlyar, 2016[74]	Cycling injuries in Southwest Colorado: A comparison of road vs trail riding injury patterns.	No OR or RR	Retrospective study, at a medical center, Moderate to severe injuries sustained on trails (trail, dirt or gravel), vs. road injuries. N = 304 patients, inc. 203 (67%) injured on trails. Description and comparison of trail- vs road-injured patients. Patients were more likely to sustain head injury while road riding (16% of road injuries vs. 6% of trail injuries, p = 0.005).
Specific body part	Nehoda et al., 2001[5]	Central liver hematomas caused by mountain-bike crashes.	Some kind of intervention, but no design and very low number of subjects	Cross-sectional study at a trauma center, followed up by recommendations and some kind of intervention study, N = 8 liver injuries caused by handle bar ends. Observation suggested increased risk when bar ends are used, public communication, followed by a decrease in bar end associated liver injury (pre: 2.7 cases/year, post: 0.33 cases/year).

APPENDIX 3 - SUGGESTED FURTHER WORK

Further analysis and interpretation of results is required for a full literature review to be submitted to *Sports Medicine.*

Methodological quality evaluation is usually quantified using scales such as Delphi[75] or PEDro.[76] No analysis of study quality was conducted in the scoping literature review.

It is suggested that a summary of this technical report be developed into a paper titled "Recreational mountain bike injury risk factors and countermeasures: A systematic review and Haddon matrix evaluation". The authors would be: Hume, P.A., Le Flao, E., Barry, M., Malpas, K.

ACKNOWLEDGEMENTS

The authors declare that there are no competing interests associated with the research contained within this technical report. The research was funded by the New Zealand Accident Compensation Corporation (ACC) Injury Prevention Group, a service group of ACC, and by the Sport Performance Research Institute New Zealand (SPRINZ), of Auckland University of Technology. According to the definition given by the International Committee of Medical Journal Editors (ICMJE), the authors listed above qualify for authorship of this technical report based on making one or more of the substantial contributions to the intellectual content of the technical report. The opinions expressed are those solely of the authors and do not necessarily reflect those of the Accident Compensation Corporation, New Zealand.

CONTRIBUTIONS

The project brief was developed by Melissa Barry and Kirsten Malpas of ACC. The project methods were developed by Patria Hume of AUT and reviewed by Melissa Barry and Kirsten Malpas. Enora Le Flao of AUT conducted the search of literature and provided initial data extraction and summary tables. Patria provided additional data analysis and wrote the first draft of the report. Enora, Melissa, and Kirsten provided editorial feedback on the report, with Patria providing the final report. Patria, Enora, Melissa, and Kirsten will co-author the final manuscript for journal submission.

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Photo acknowledgement: Haydn Kevin Bradfield, 2017